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Design and Experiment of Differential Speed Snapping Rollers for Horizontal Roller Corn Harvester

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Abstract. This paper analyzed some conditions which cause grain breakage and grain loss during harvesting process of horizontal roller corn harvester. If the transmission rate between two snapping rollers can be changed, the grain breakage and grain loss can be solved at a certain level. So a pair of differential speed snapping rollers for horizontal roller corn harvester was designed, and the work effects between the constant speed snapping rollers and the differential speed snapping rollers were compared by using software CATIA and ADAMS, and found that the rolling speed of inner snapping roller is 500r/min, and the outer snapping roller is 460r/min are the best transmission rate. Finally, a physical experiment was conducted to certificate the simulation effect. In or-der to avoid some disadvantages of field experiment and soil bin experiment in laboratory, half laboratory and half field environment were used in this physical experiment. As a result, the physical experiment confirmed that the analyses above and the simulation by ADAMS were valid. In conclusion, it is an effective method to reduce grain breakage and grain loss by using differential speed snapping rollers for horizontal roller corn harvester.

Keywords. Snapping rollers, horizontal roller, speed, corn harvester, grain breakage, grain loss, ADAMS

1 Introduction

Corn is a main crop in China, the plant area is nearly 25 million hectares all over the China (Lisowski et al. 2012), Planting and managing are basically mechanization through the whole process of producing corn, only the harvesting process mechanization's level is relatively lower (Kathirvel et al. 2010; Tong et al. 2007). Now, all kinds of corn harvesters are being developed, horizontal roller corn harvester is one main kind of these researching types. There are several factors which can't satisfy the subscribers such as missing harvesting, jams between the snap-ping rollers, losing grain and grain breakage and so on.

There are two main reasons causing the grain breakage. Firstly, the collision be-tween corn ear and snapping rollers when the corn ear goes down rapidly that causes grain breakage. Secondly, the rolling friction between corn ear and snapping rollers causes grain breakage, too (Diao et al. 2008; Zhang et al. 2011). The grain breakage will influence the corn storage quality severely (Zhao et al. 2011).

There are more than ten thousand 4YZB-2 corn harvesters which were produced by Jixin Agricultural Company in Jilin Province, China. Some corn ears can't drop into the lift conveyer immediately after being snapped through

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autumn-field tests on 4YZB-2 corn harvester from 2010 to 2012. It is because that corn ear's axis is parallel with snapping rollers' axes when it is being snapped, so the corn ear will roll with the snapping rollers in the space of two snapping rollers, it will drop into the lift conveyer only by some vibrating after a certain time.

2 Materials and methods

2.1 Analyses and design of differential speed snapping rollers

As shown in figure 1 (Jia et al. 2015), while the corn ear is rubbing in the space of two snapping rollers, grain breakage and grain loss will appear, it is a big problem for storage.

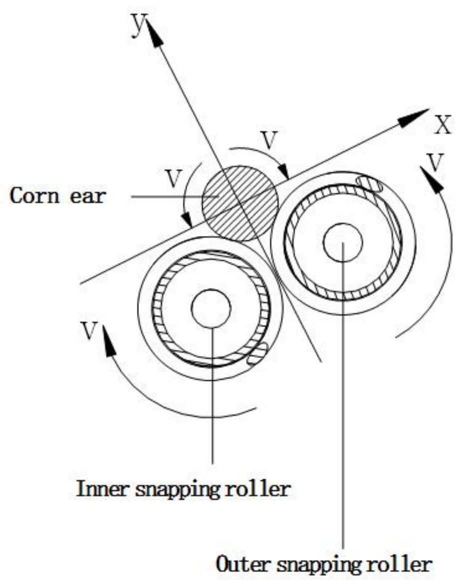

Fig.1 Sketch map of friction between a corn ear and snapping rollers

Although the outer snapping roller is higher than the inner snapping roller of horizontal roller corn harvester, this design is convenient for corn ears drop into the lift conveyer, when the diameter of corn ear is relatively small, the corn ear is more likely to get into the space of two snapping rollers, and it is hard for the corn ear to drop into the lift conveyer. As shown in figure 1, the corn ear has an inverted hour movement tendency when the corn ear contacts with inner snapping roller, at the same time, the corn ear contacts with outer snapping roller, so it also has a clockwise movement tendency (Du et al. 2012). But if the corn ear has acceleration along with the negative direction of "x" axis as shown in figure 1, it is a good tendency for the corn ear to drop into the lift conveyer.

$$a_{x-} = \frac{dV}{dt}\cos\alpha = \frac{d\sqrt{(\omega r)^2 + [(g\sin\theta - \mu g\cos\theta)t]^2}}{dt}\cos\alpha \cdots (1)$$

$$a_{x+} = \frac{dV}{dt}\cos\alpha = \frac{d\sqrt{(-\omega r)^2 + [(g\sin\theta - \mu g\cos\theta)t]^2}}{dt}\cos\alpha \cdots (2)$$

where: 'a_{x-}' is corn ear's acceleration along with negative direction of "x" axis; 'a_{x+}' is corn ear's acceleration along with positive direction of "x" axis; 'θ' is the angle between snapping rollers and ground; 'α' is the angle between corn ear's resultant velocity and "x" axis; 'μ' is friction coefficient between corn ear and snapping roller; 'ω' is rolling speed of snapping roller; 'r' is radius of a snapping roller including helix outshoot; 't' is corn ear's rolling time.

According to the two equations (Jia et al. 2015) above, if two snapping rollers have the same rolling speed, the positive direction acceleration of "x" axis and negative direction acceleration of "x" axis for the corn ear is the same. Only when two snapping rollers' rolling speed isn't equal, there is a tendency for the corn ear which axis is parallel with snapping rollers' axes to drop into the lift conveyer. The space between two snapping rollers of 4YZB-2 corn harvester is 17 mm, and helix outshoot's diameter is 8 mm, so interference will not occur to the helix outshoots. One snapping roller provides impetus, and another is driven by it, they are transmitted through cylindrical gears. The constant speed snapping rollers' numbers of teeth are 1:1, in order to achieve differential speed, we selected different numbers of teeth for the two cylindrical gears.

2.2 Simulation analyses and experiment

2.2.1 Work effect analyses for constant speed and differential speed snapping rollers

Firstly, two models for constant speed and differential speed snapping rollers were built respectively by using software CATIA, according to 4YZB-2 corn harvester's real condition, the outer snapping roller provides impetus, the inner snapping roller is driven. The two cylindrical gears' numbers of teeth for constant speed snapping rollers are all 27, the cylindrical gear's number of teeth for differential speed snapping roller which provides impetus is 27, too, the cylindrical gear's number of teeth for differential speed roller which is driven is 23, namely, the transmission rate between two snapping rollers is 23:27. The center to center spacing of differential speed snap-ping rollers and conventional constant speed snapping rollers are the same. Secondly, models of a corn stalk and a corn ear were built, the height of corn stalk is 2000 mm, and the height from ground to corn ear is 1050 mm. The axis of corn ear is between the two snapping rollers' axes in load module of CATIA, there is 55 degrees between snapping rollers' axes and the corn stalks' axis.

The load map of CATIA was opened by using software SIM DESIGNER, and constraint conditions were added for them, then it was been saved as *.cmd file which could be read by software of ADAMS subsequently, finally, it was transmitted to ADAMS for simulation analyses. We selected cast iron as the snapping rollers' material in ADAMS, and the materials for the corn stalk and the corn ear are all user-defined materials. The density of corn stalk was 388Kg/m3. Young's modulus of elasticity was 10Gpa. Poisson ratio was 0.35. The density, Young's modulus of elasticity and Poisson ratio of corn ear was 438Kg/m3, 11Gpa and 0.33 respectively. In order to simulate the connection of corn ear and corn stalk, we used Bushing Connection in ADAMS, the aim was to build a three directions force which was direct proportion with relative displacement and relative velocity between corn ear and corn stalk (Ono et al. 2013). As we all known, movement is relative, so corn stalks' movement relative to snapping rollers could be simulated as forward speed of corn harvester.

The constant speed snapping rollers' rolling speed was 450r/min, and forward speed of corn stalk was 3.67Km/h. Lasting time of simulation was 2 second, and step size was 0.01 second. Contact force between corn ear and snapping rollers as shown in figure 2.

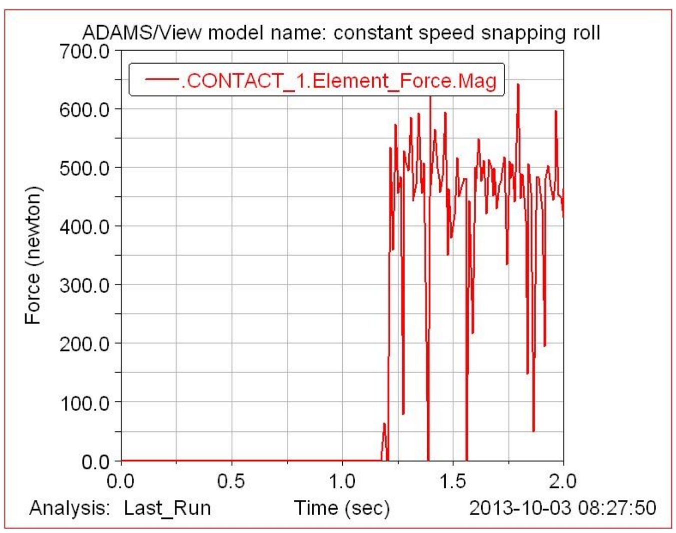

Fig.2 Contact force between corn ear and snapping rollers for constant speed snapping roller

As for differential speed snapping rollers, we selected the rolling speed of snap-ping roller which provided impetus was 450r/min, the other simulation conditions were the same with the simulation conditions of constant speed snapping rollers. Contact force between corn ear and snapping rollers as shown in figure 3.

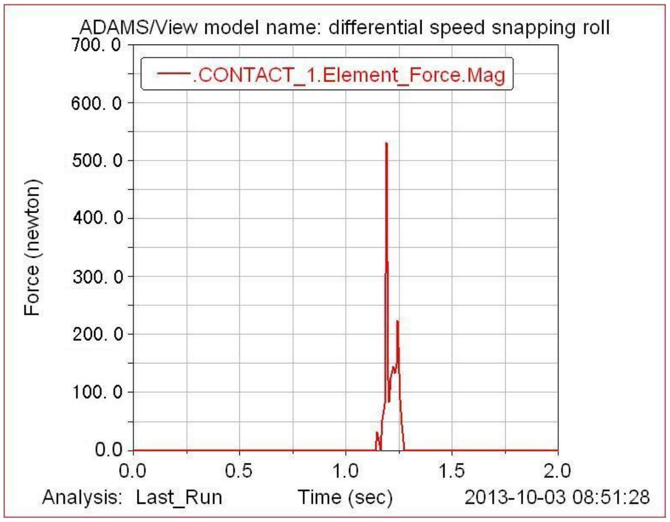

Fig.3 Contact force between corn ear and snapping rollers of differential speed

Snapping rollers

2.2.2 Experiment to define best rate of rolling speed

According to the simulation results, the shorter lasting time of non-zero contact force, the shorter contact time between corn ear and snapping rollers, so smaller of grain breakage and grain loss. In order to minimize these losses, an experiment to de-fine best rate of rolling speed should be done. The rolling speed of outer snapping roller should be smaller than the inner snapping roller according to equations (1) and (2) which were mentioned above, and because snapping rollers are transmitted by cylindrical gears, the modulus and number of teeth should take into consideration. So we took a numerical value every 50r/min for the inner snapping roller and every 30r/min for the outer snapping roller in the simulation experiment.

2.3 Physical experiment

The aim of doing physical experiment was to validate this design and the simulation results. This experiment was based on the 4YZB-2 corn harvester, we used a pair of cylindrical gears which transmission rate is 25:23 according to the simulation result. As shown in figure 4.

Fig.4 Transmission part of differential speed snapping rollers

Liberation couldn’t be taken into consideration in soil bin test, and weather condition is a big problem to field experiment, so we took half laboratory environment and half field environment in this experiment. In order to simulate standing corn stalks, we designed a rail to hold corn stalks, and the space between each stalk was 200 mm. As shown in figure 5.

Fig.5 Half laboratory environment and half field environment

The corn in this experiment is one main kind of corn varieties which is famous in Siping City Jilin Province of China in recent years, and its name is Jidan 209. The optimum working parameters of 4YZB-2 corn harvester was selected while the experiment was going on. The forward speed was approximately 0.6m/s, the angle between the snapping rollers and the ground was 35 degrees, and the rolling speed of snapping rollers was about 400r/min. Two experiments which used differential speed snapping rollers and constant speed snapping rollers were done respectively to compare the work effects of these two kinds of snapping rollers. There were 300 corn stalks in each experiment, and the experiment index was grain breakage.

3. Results and discussion

3.1 Simulation part

As can be seen from figure 2, in the neighbor of 1.25 second, the contact force increased significantly, it indicated that snapping period started, the contact force fluctuated subsequently. In other words, the corn ear didn’t drop into the lift conveyer. When the corn ear’s axis was parallel with the space axis of constant speed snapping rollers, the corn ear would rub in the space rather than drop into lift conveyer immediately, grain breakage and grain loss would occur during this period. Figure 3 showed that from 1.25 second approximately, the contact force increased significantly, too. But it disappeared only after a short period. Namely, the corn ear dropped from snap-ping rollers, and it was transmitted by the conveyer subsequently.

Horizontal roller corn harvester has a function of removing pellicle from corn ears, and the function is very evident especially for the full ripeness corn ears (Jia et al. 2010; Besselink et al. 2004). So when the friction time of corn ear and snapping rollers is too long, the grain will contact with the snapping rollers, and if the grain was broken, the probability increases severely of musty, which is can’t be tolerant for storage. On the contrary, if the corn ear could drop from the snapping rollers immediately after being snapped, the grain can be protected well.

As for the best rate of rolling speed, simulation result was shown in table 1.

Table.1 Friction time and rolling speed of inner and outer snapping roller

Friction time（s）	Rolling speed of inner snapping roller (r/min)	Rolling speed of outer snapping roller (r/min)
0.2	450	370
0.15	450	400
0.23	500	430
0.13	500	460
0.25	550	490
0.3	550	520

0.3	600	550
0.3	600	580

As can be seen from table 1, the best rolling speed of inner snapping roller is 500r/min, and the best rolling speed of outer snapping roller is 460r/min, the friction time was only 0.13 second. So it is the shortest time at these rolling speeds.

3.2 Physical experiment part

There were 11 corn ears occurred grain breakage in the whole 300 corn ears which harvested by the constant speed snapping rollers, so the grain breakage rate was 3.67%. The grain-breakage corn ear was shown in figure 6.

Fig.6 Corn ear which occurred grain breakage

But there were zero corn ear occurred grain breakage in the whole 300 corn ears which harvested by the differential speed snapping rollers. So the grain breakage rate was zero. Another discovery in this experiment was that differential speed snapping rollers have kneading function to the stalks, it is a good effect on the returning work subsequently (Heijting et al. 2009; Montes et al. 2006). The corn stalks kneaded as shown in figure 7.

Fig.7 Corn stalks kneaded by differential speed snapping rollers

Because inner and outer snapping roller has different rolling speed, so two snap-ping rollers have different vibration frequencies, and it is to say the probability of resonance decreases (Dawkins et al. 2012). This is benefit to avoiding sealing-off for weld spots in the cut-ting table, and it also has a good effect on prolonging corn harvester’s life-span (Jia et al. 2013).

4.Conclusion

Grain breakage is a fatal threat to storage, and it is also a severe loss for farmer's economical benefits. This problem can be solved at a certain level by changing the rolling speed of snapping rollers of horizontal roller corn harvester. Actually, it is because the friction time of corn ear and snapping rollers has been changed. A best rolling speed rate was obtained through simulation by using some computer software such as CAITA and ADAMS, the best rolling speed of inner snapping roller is 500r/min, and the best rolling speed of outer snapping roller is 460r/min. The physical experiment also certificated that using differential speed snapping rollers is a good way to reduce the grain breakage.

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